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13 April 1994

Dr. Thomas H. Kinder
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Dear Dr. Kinder,

Enclosed you should find a copy of the final report for the Office of Naval Research grant N00014-921-J-1022, Astoria Canyon Circulation Analysis.

Sincerely,

Barbara Hickey

Barbara Hickey
School of Oceanography

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cc:  Administrative Grants Officer
     Office of Naval Research

     Director, Naval Research Laboratory

     Defense Technical Information Center
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ASTORIA CANYON CIRCULATION ANALYSIS

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Goals

The long term goal of this project is to understand the dynamics of circulation within coastal submarine canyons and to understand the effect of canyons on the local shelf and slope circulation and water mass properties.

Objectives

The specific objectives are

1.) to describe the spatial and temporal structure of the mean and time-dependent flow near and within a relatively narrow submarine canyon (width~internal Rossby radius); and,

2.) to understand the time-dependent response of the velocity and density fields within the canyon to perturbations in the flow field incident on the canyon.

Approach

The work in this project addresses the classic problem of time-variable, stratified flow over steep topography, in this case, a submarine canyon. Available data consists of an array of moored current meters and two CTD surveys from the vicinity of Astoria submarine canyon during the period May-August, 1983. The data were obtained at spatial scales sufficient to resolve the circulation over the steep slopes of the canyon. The time period sampled with the moored array includes two striking upwelling events and at least one downwelling event that strongly force the circulation and the density field. A purely statistical analysis demonstrated the existence of a topographically trapped cyclonic (counterclockwise) circulation pattern over the canyon for both the mean and the fluctuating flow with the strongest cyclonic circulation lagging the maximum velocity in the incident flow by one or more days. The mechanism for the vortex development, and, in particular, the lag between the strength of the incident flow and that of the vortex could not be explained by the purely statistical approach. This study has extended the statistical results with a detailed examination of vertical and lateral displacement of flow layers over and within the canyon.

Tasks

To explain the development of the counterclockwise flow pattern within and over the canyon, we have used the concept of conservation of potential vorticity; i.e., as flow layers are stretched or compressed, the relative vorticity in that layer must change to conserve vorticity. For example, a layer that stretches as it passes into deeper depths will develop a counterclockwise circulation pattern. Flow layers can also be stretched (or compressed) during upwelling (downwelling). Stretching vorticity was estimated from both CTD and moored array data, using a monthly mean temperature profile as an upstream condition. To attempt to remove effects of regional upwelling, data from the Washington shelf/slope during an upwelling event in 1982 were also used as an upstream condition. Relative vorticity was estimated directly from the moored velocity data. Canyon-specific effects, such as stretching of flow layers as they pass over the canyon, were separated from regional processes such as upwelling using light attenuation data (to trace turbid shelf water) as well as time series of temperature within the canyon. The research is continuing with an assessment of the nonlinearity of the flow field and investigation of how flow incident along the slope interacts with the canyon.

Results

The analysis demonstrated that cyclonic (counterclockwise) flow was generated both by stretching of flow layers as they pass over the canyon and by stretching of layers during the upwelling process. During the initial phase of an upwelling event, flow below the canyon lip is up-canyon at all locations (Fig. 1) and upwelling is simultaneous and uniform to zero order within the canyon. Some shelf water falls ~50m into the canyon, resulting in a local increase in cyclonic vorticity and hence counterclockwise circulation (Fig. 2). As upwelling continues, stratification near the depth of the canyon lip increases by at least a factor of three, effectively capping the canyon from the overflowing water. The overflowing layer still stretches downward as it passes over the canyon, but the deflection is only about 25m. Relative vorticity is less anticyclonic or even cyclonic in that layer but is more anticyclonic directly below that layer relative to that due to the regional upwelling. Maximum stretching of flow layers within the canyon occurs after the upwelling relaxes, so that the strongest counterclockwise circulation within the canyon lags the maximum in overflowing velocity by 1-3 days (Fig. 1). Flow also crosses canyon isobaths under downwelling conditions; i.e., when flow is incident on the canyon from the south rather than from the north. Flow layers are stretched and hence the cyclonic circulation increases over and also within the canyon during such events. However, the cyclonic pattern is confined to the upper layers of the canyon.

Accomplishments

For the first time, the three-dimensional, time-dependent structure of the mass, velocity and vorticity fields within a narrow, steep submarine canyon have been described in sufficient detail to understand the response of the canyon to large perturbations in the incident flow field.

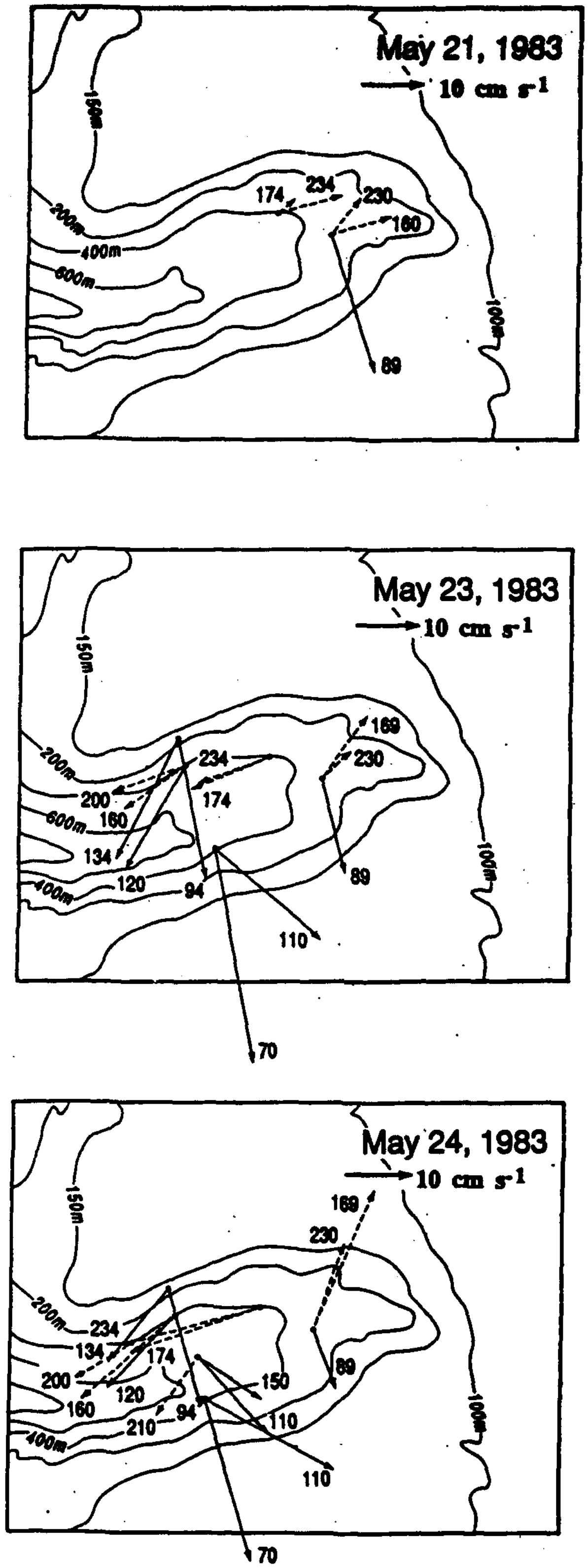

Figure 1. Time series of velocity vectors in the vicinity of Astoria submarine canyon during strong upwelling. Instrument depth is indicated near the tip of each vector. Solid (dashed) vectors are used for depths above (below) the canyon rim. At the time of maximum upwelling (May 21) inflow into the canyon occurs at all locations below its rim. However, as upwelling relaxes, a cyclonic (counter-clockwise) circulation pattern develops within and over the canyon.

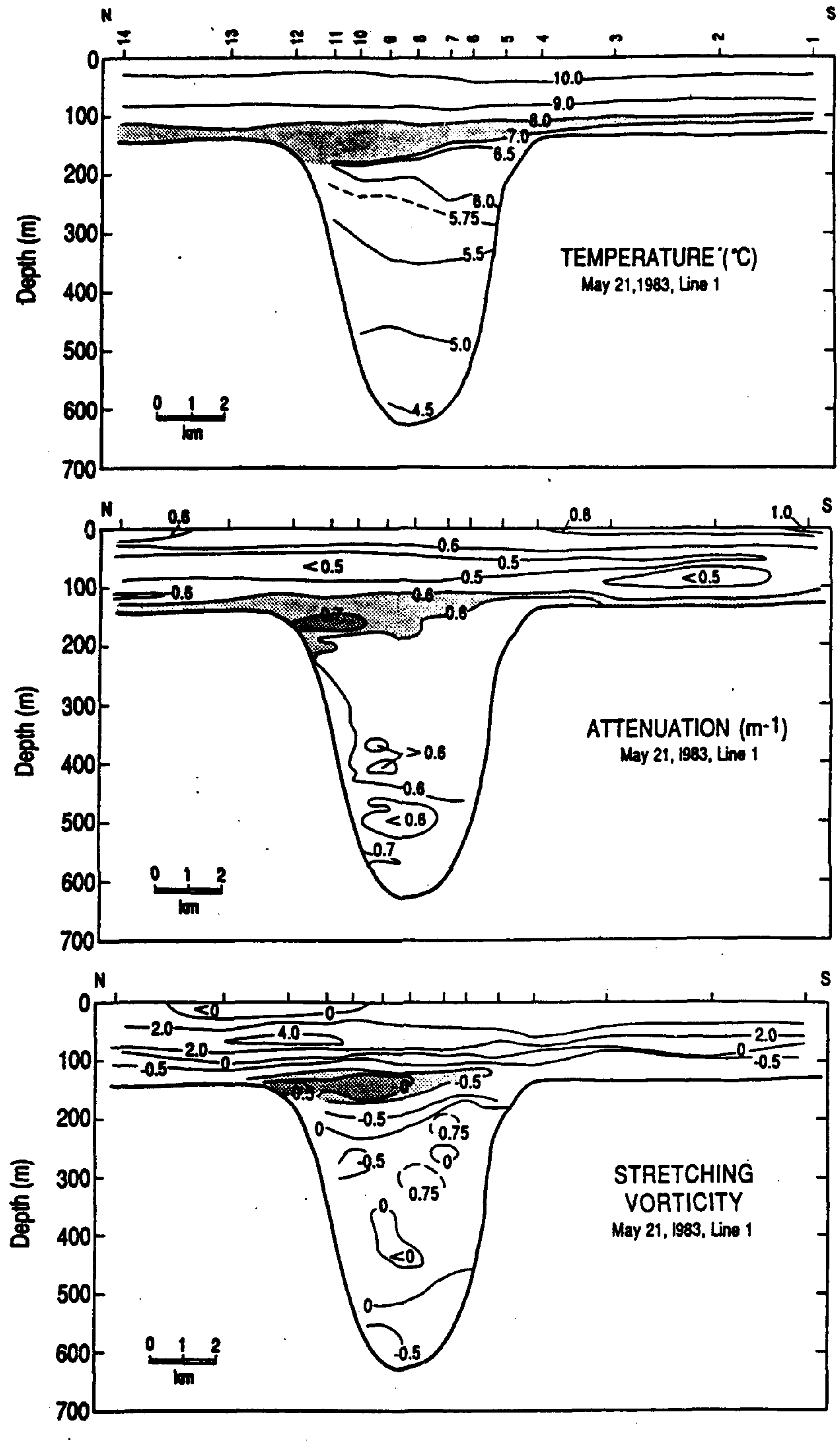

Figure 2. Temperature (°C), attenuation (m^{-1}) and stretching vorticity (relative to the Coriolis parameter) on a section across Astoria submarine canyon during a strong upwelling event. An intermediate nepheloid layer separates turbid water that has fallen into the canyon on its north side from cleaner water being upwelled within the canyon. Cyclonic vorticity is observed not only in the region where water has fallen into the canyon, but also deep within the canyon where upwelling has stretched individual flow layers. Note that positive values of stretching vorticity in the surface layers are likely due to interannual variability of regional water masses.